

## REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-99-

0183

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering the data, reviewing and completing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Project Director (0304-0188), Washington, DC 20503.

and reviewing  
information

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 1999		3. REPORT TYPE AND DATES COVERED Final Technical Report 1 Sep 93 to 30 Sep 98	
4. TITLE AND SUBTITLE Improved Assessment of Software Reliability				5. FUNDING NUMBERS F49620-93-1-0507	
6. AUTHOR(S) N. D. Singpurwalla				3484/ZS AASERT 93	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) George Washington University Washington, DC 20052				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NM 801 N. Randolph Street, Room 732 Arlington, VA 22203-1977				10. SPONSORING/MONITORING AGENCY REPORT NUMBER  F49620-93-1-0507	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION AVAILABILITY STATEMENT  Approved for Public Release; Distribution Unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Research under this grant has dealt with the general area of reliability theory and quality control, with emphasis on problems emanating from software engineering, software reliability and testing. In all, 6 papers have been published or accepted for publication in the open literature. An innovation has been the development of the topic of warranties which seems to have growing importance especially with regard to military hardware and software systems.					
19990803 086					
14. SUBJECT TERMS				15. NUMBER OF PAGES 4	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  Unclassified		18. SECURITY CLASSIFICATION OF THIS PAGE  Unclassified		19. SECURITY CLASSIFICATION OF ABSTRACT  Unclassified	
				20. LIMITATION OF ABSTRACT  UL	

# **FINAL TECHNICAL REPORT**

**N. D. Singpurwalla  
The George Washington University  
Washington, DC 20052**

**AFOSR F49620-93-1-0507**

**DNC QUALITY INSPECTED 8**

# FINAL TECHNICAL REPORT

AFOSR F49620-93-1-0507

Nozer D. Singpurwalla, Principal Investigator

Research under the above grant deals with the general area of reliability theory and quality control. An emphasis here is on problems emanating from the area of software engineering, especially software reliability and software testing. In all 6 papers have been published or accepted for publication in the open literature, and 2 are currently under review. In the latter category, one of the papers deals with the topic of *warranties*, an issue which is relatively less formally researched but which appears to be growing in importance with respect to both military and commercial systems (to include both hardware and software).

## 1. Software Certification and Reliability Growth.

In the general area of software reliability 2 papers (see references 2 and 5) have been written, one of which has appeared in print and the other accepted for publication. The first one deals with the important problem of how much testing needs to be done to a piece of software before it is released for use. The problem is formulated as one involving decision under uncertainty and a mathematical expression for obtaining the optimum test time has been developed. The approach has been codified for use on a personal computer and this software is included in a package of programs for reliability analysis that is currently being developed. A use of this approach calls for a specification of the costs of testing and the costs of failure during operation. Unfortunately, only the case of single stage testing has been rigorously addressed. The more realistic case of sequential testing poses horrendous technical difficulties and remains to be addressed. Work on this topic continues.

plans) and implemented for use.

### 3. Accelerated Life Testing

Accelerated life testing is routinely done in reliability assessment. The existing procedures for inference from accelerated tests are predominantly non-Bayesian; their disadvantage has been an inability to incorporate engineering judgment into the analysis of data from accelerated tests. The use of such judgments is the operating norm in practical applications of accelerated tests. Viewing an accelerated test as an operation in filtering, with suitable priors to reflect engineering judgment offers hope, and a proposal to do the above was advocated by the PI. An implementation of this approach to some real live data from a biological context was undertaken under the aegis of this grant; see reference 3. The aim here was to demonstrate the feasibility of the proposed approach and to describe the practical nuances that occur when one attempts to undertake it.

### 4. Dependence in Reliability

The notion of dependence is central to the current research in reliability theory; the usual assumption of independence has resulted in unsatisfactory assessments. The fact that dependence is a *conditional* notion has not been explicated in the literature in reliability. Under the aegis of this grant (see reference 1), such conditioning is emphasized and the idea is further explored by making the conditioning parameter random. This work is of a foundational nature.

### 5. Warranties

Whereas consumers are used to acquiring products that are warranted by the manufacturer, the government, particularly DOD, may soon be moving more aggressively in that direction. It is very

likely that warranties may be mandated in the future procurement activities of the DOD. The problem of optimum warranties is a multi-disciplinary one, which involves among other things, issue of reliability and renewal theory. Under the aegis of this grant the problem of warranties has been scoped out (see references 6 and 8) and specific issues germane to the problem addressed. Of particular interest is the need to develop a new class of failure models that are indexed by two scales, time and usage. Work in this area is currently in progress. The topic of warranties promises to become a full-fledged multidisciplinary research area in the mathematical sciences.

## References

### Papers

1. Brady, B. and Singpurwalla, N. D. (1991). Stochastically Monotone Dependence. In *Topics in Statistical Dependence*. The Institute of Mathematical Statistics, Lecture Notes/Monograph Series (Block, H. W., Sampson, A. R., and Savits, T. H., Eds.), pp. 93-102.
2. Singpurwalla, N. D. (1991). Determining an Optimal Time Interval for Testing and Debugging Software. *IEEE Transactions on Software Engineering*, Vol. 17, No. 4, pp. 313-319.
3. Singpurwalla, N. D. and Chen, J. (1991). Filtering, Smoothing, and Extrapolations in Dose-Response Experiments with Application to Data on Respiratory Tumors of Rats. In *Bayesian Inference in Statistics and Econometrics: Proceedings of the Indo-U.S. Workshop, 1988*. New York: Springer-Verlag. To appear.
4. Lindley, D. V. and Singpurwalla, N. D. (1991). On the Amount of Evidence Needed to Reach Agreement Between Adversaries. To appear in *JASA*; December 1991.
5. Singpurwalla, N. D. and Soyer, R. (1992). Nonhomogeneous Autoregressive Processes for Tracking Reliability Growth, and Their Bayesian Analysis. To appear in *JRSS(B)*, Vol. 54, No. 1, 1992.
6. Singpurwalla, N. D. and Wilson, S. (1992). Warranties. To appear in *Bayesian Statistics 4*. Edited by J. Berger, J. Bernardo, P. Dawid and A. Smith.

### Technical Reports

7. Lindley, D. V. and Singpurwalla, N. D. (1991). Adversarial Life Testing. Technical Report GWU/IRRA/Serial TR-90/5. The George Washington University, Washington, DC. Under Review.
8. Singpurwalla, N. D. and Wilson, S. (1991). The Warranty Problem: Its Statistical and Game Theoretic Aspects. Technical Report GWU/IRRA/Serial TR-91/1. The George Washington University, Washington, DC. Under Review.